METHODOLOGY FOR CO-REGISTRATION OF IMAGE STACKS USING ADOBE PHOTOSHOP©

SUMMARY OF THE ROBERTS DIFFERENCE STACKING METHOD

This method of stacking astronomical images, using Adobe Photoshop© to enhance detail and reduce image grain, is due to Roberts (2003). According to Roberts, Photoshop© is not designed to ADD digital images in the same manner as professional astronomical imaging processing software. However, Photoshop is capable of combining *pairs of images*, the result of which, according to the method's author, is identical to stacking two images with imaging processing software. A *stack* consists of a base image (opacity 100%) and an image overlay where the opacity is set at exactly 50%. Thus, the image overlay's pixel value masks the underlying base image pixel value by 50%, and the sum of both is equivalent to the ADD function in scientific imaging processing software.

The key principle of this method is to iteratively stack multiple pairs of previous, similarly processed, image stacks. Each stack of two images results in a single image. Another stack of two other images results in another single image. If these two stacks are themselves stacked, the result is a composite of a total of four images; likewise, stacking a pair of four-image stacks results in a composite of eight images, and so forth. Therefore, to properly use the method requires a total of 2^k primary images, where k equals the number of stacking levels.

Imagine a processing tree where each single image and each successive paired image stack is represented by a box (*Fig. 1*). It is helpful to have a method for keeping track of what branch (or level) you are on. One naming convention that I use is described below.

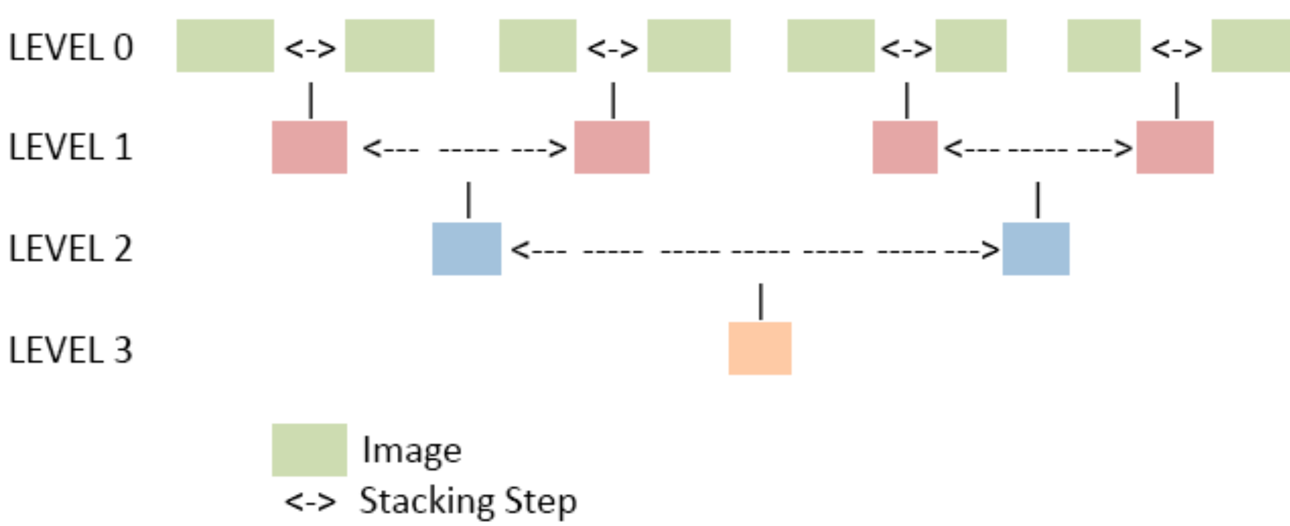


Fig. 1 – Processing tree for eight rotated and masked images (Level 0). At the base is the final stacked image (box at Level 3) resulting from stacking a pair of images (two boxes at Level 2) that, in turn, were the result of stacking a pair of images (Level 1). The connections are analogous to branches of a tree.

DEFINITION OF TERMS

Ephemeris – A table of attributes of an astronomical object at a specified time. See **APPENDIX A** Ephemeris of Solar System Dynamics for details.

Image – A FITS image saved as a 16-bit TIFF file. The dimensions of the image are 512px x 512px.

Layer – A component of a Photoshop© *.psd* file that contains graphical information (such as raster, vector, point or text) in a planar format, analogous to a semi-transparent acetate overlay.

Level – A hierarchical designation of similarly processed stacks in the processing tree. By definition, the original image files are at Level 0. When rotation and/or registration and stacking steps have been completed on a pair of Level 0 files, the result is a Level 1 file.

Overlay Mask – A PS layer consisting of a black background with a circular cutout. The cutout diameter (in pixels) is the diameter of the Venus image for the stack being considered.

PS – Adobe Photoshop©

Pair index – After two images are stacked, the pair index *n-m* refers to the base image (*n*) and the overlaid image (*m*). See **A USEFUL NAMING CONVENTION** section below.

Rectify – The general process needed to rotate and, if necessary, to scale an image

Register – Aligning two images so that corresponding features of each have the same *x*- and *y*- image coordinates

Rotate – Rotation (in degrees) of the image about its center. A typical requirement might be to rotate the *y*-axis to be parallel to the N-S meridian

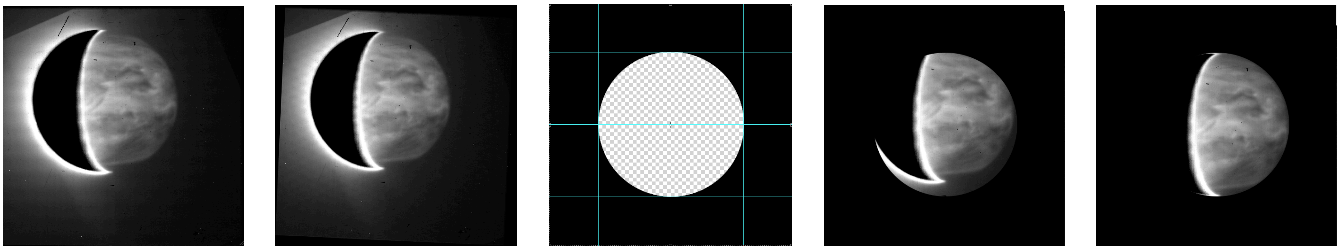
Stack – Merging of two registered images, typically **Flatten**ed by PS to reduce file size

TYPOGRAPHIC AND OTHER CONVENTIONS USED HERE

❋ IMPORTANT STEP!
File name example: ***/LEVEL 0 TIF IMAGES/0-1.tiff***
PS command example: **Layer>Layer From Background**
Layer name example: ***Layer 0-1 rot***
Center of mask: *x*: 255px; *y*: 255px defined by convention

PROCESSING STEPS

The following lists the basic processing steps necessary to stack two images, such that the polar axes of Venus in the resultant image are oriented vertically and the extraneous surrounding sky around Venus is masked. Rectification is assisted by using a centered and circular opening of a mask. *Fig. 2* shows the sequence of the processing steps necessary to rotate and center each image.



(a) (b) (c) (d) (e)

Fig. 2 – Sequence of steps required to rectify and register an image: (a) Convert FITS image file to TIFF image file; (b) Rotate image so that N-S direction is vertical; (c) Create a centered mask overlay whose circular opening is the same width as the diameter of Venus; (d) Move the image file under the mask so that it is centered on the opening; (e) Flatten image and mask.

STEP 1 -- Convert FITS files to TIFF format

In FITS Liberator (or similar viewing program) adjust contrast, if necessary, convert all ***.fits*** files to 16-bit ***. tiff*** files. Contrast can be also adjusted in Photoshop

STEP 2 -- Create Mask

This step creates a mask that is useful for centering images and removing distracting and extraneous sky glow around Venus. The diameter of the circular hole in the mask is determined experimentally from an image taken during the time interval of exposure or from an ephemeris of Venus; see APPENDIX A. In this example, assume that the diameter is 306 px.

Create a base layer	**File>New**	Name: **Background** Size: **512 px x 512 px** Background color: **Black** Foreground color: **Black**
	Layer>New>Background From Layer	
Save file	**File>Save As>*BlackBackground.psd***	
Set six guides (see *Fig. 2c*)	**View>New Guide**	Orientation: **Vertical** Position: x = 102px, 255px, 408px Orientation:**Horizontal** Position: y = 102px, 255px, 408px
Select Elliptical Marquee Tool		
Draw a circle		
In Toolbar, set size	Style: **Fixed Size**	Width: **306 px** Height: **306 px**
Select Move Tool		
Drag box so that the circle is approximately bounded by the guides		
❋ Finalize centering	Use cursor keys to move the circle ± 1px at a time	
Cut hole in mask	**Edit>Cut**	
❋ Rename layer	***Mask306px***	
Save file	**File>Save As>*Mask306px.psd***	

STEP 3 -- Rotate Image (optional)

Open TIFF image	**File>Open>*0-1.tiff***
Flip image option	**Image>Rotate Canvas>Flip Canvas Horizontal**
Rotate image	**Image>Rotate Canvas>Arbitrary…** Angle: **2.5° CW**
Create new layer	**Layer>New>Layer From Background**
❈ Rename new layer	***Layer 0-1 rot***
Select layer	**Select>All**
Copy layer to clipboard	**Edit>Copy**
Save as new file	**File>Save As**: ***0-1rot.tif*** Format: **TIFF**
Close file	**File>Close**

STEP 4 -- Align with Mask

Open black background layer	**File>Open>*BlackBackground***
Open overlay mask of 306px diameter	**File>Open>*Mask306px***
Move layer ***Mask306px*** to top	
Paste rotated image from clipboard	**Edit>Paste**
❈ Rename new *Layer1*	***Layer 0-1 rot***
Select layer ***Layer 0-1 rot***	
Select the Move tool	

Drag layer to the approximate center of the mask's opening (see *Fig. 2d*)

Finalize centering (*Fig. 2e*)	Use cursor keys to move image ± 1px at a time
Save as new file	**File>Save As: *0-1reg.tif***
Flatten image and mask	**Layer>Flatten Image**
Rename *Background* layer	***Layer 0-1 reg flat***
Save	**File>Save**

❈ Repeat **Rotate Image** and **Align with Mask** steps for ***0-2.tif***

STEP 5 -- Registration and Stacking of Image Pairs

❈ Once image pairs have been individually processed, they may be registered and stacked

Open base layer	**File>Open>*0-1reg.tif***
Open overlay layer	**File>Open>*0-2reg.tif***

Overlay layer is now **Active**

❈ Make sure this layer has a unique name (e.g., ***Layer 0-2 reg***)

Select layer	**Select>All**
Copy layer to clipboard	**Edit>Copy**
Close overlay file	**Close**

Base image is now **Active**

Paste the previously copied image	**Edit>Paste**
❈ Rename *Layer 1*	***Layer 0-2 reg***

Select ***Layer 0-2 reg*** and move to top

In *Layers* palette, change Layering Mode from *Normal* → *Difference*
Image should now be nearly black with some gray pixels
❋ Align images with cursor keys ± 1 px at a time in all directions to minimize the number of gray pixels
In *Layers* palette, change Layering Mode from *Difference* → *Normal*
❋ Set *Opacity* of top layer to exactly 50%

Flatten image layers	**Layer>Flatten**
❋ The flattened image layer name is *Background*	
Rename *Background* layer	***Layer 1-1***
Save registered image	**File>Save As>** /***LEVEL 1 TIF Images/1-1.tif***

A USEFUL NAMING CONVENTION

The stacking methodology registers pairs of images and combines the pixel values into a composite image. It is helpful to use an unambiguous naming convention for the processed and stacked images. One simple convention is ***n-m.tif*** where ***n*** is the level of the iteration (*0* indicating the original image, *1* being the first iteration, *2* the second, etc.) and ***m*** is the sequence index of the original (that is, not stacked) registered images.

Example: Chose four original images, say ***0-1.tif***, ***0-2.tif***, ***0-3.tif*** and ***0-4.tif***. The first two are paired and registered; name the flattened result ***1-1.tif***. The second pair, ***0-3****.tif* and ***0-4.tif*** are paired, registered and flattened as ***1-2.tif***. Then ***1-1.tif*** and ***1-2.tif*** are co-registered and flattened; the result is named ***2-1.tif***.

0-1.tif + ***0-2.tif*** -> ***1-1.tif***	LEVEL 0 pair yields LEVEL 1 image
0-3.tif + ***0-4.tif*** -> ***1-2.tif***	LEVEL 0 pair yields LEVEL 1 image
1-1.tif + ***1-2***.tif -> ***2-1.tif***	LEVEL 1 pairs yield LEVEL 2 image

If eight images are considered, then the result would be:

0-1.tif + ***0-2.tif*** -> ***1-1.tif***	LEVEL 0 pair yields LEVEL 1 image
0-3.tif + ***0-4.tif*** -> ***1-2.tif***	LEVEL 0 pair yields LEVEL 1 image
0-1.tif + ***0-2.tif*** -> ***1-3.tif***	LEVEL 0 pair yields LEVEL 1 image
0-7.tif + ***0-8.tif*** -> ***1-4.tif***	LEVEL 0 pair yields LEVEL 1 image
1-1.tif + ***1-2.tif*** -> ***2-1.tif***	LEVEL 1 pairs yield LEVEL 2 image
1-3.tif + ***1-4.tif*** -> ***2-2.tif***	LEVEL 1 pairs yield LEVEL 2 image
2-1.tif + ***2-2.tif*** -> ***3-1.tif***	LEVEL 2 pairs yield LEVEL 3 image

Note that in this example, eight images are stacked to produce the final image ***3-1.tif*** in seven steps. The diagram for the processing tree is shown in *Fig. 3*.

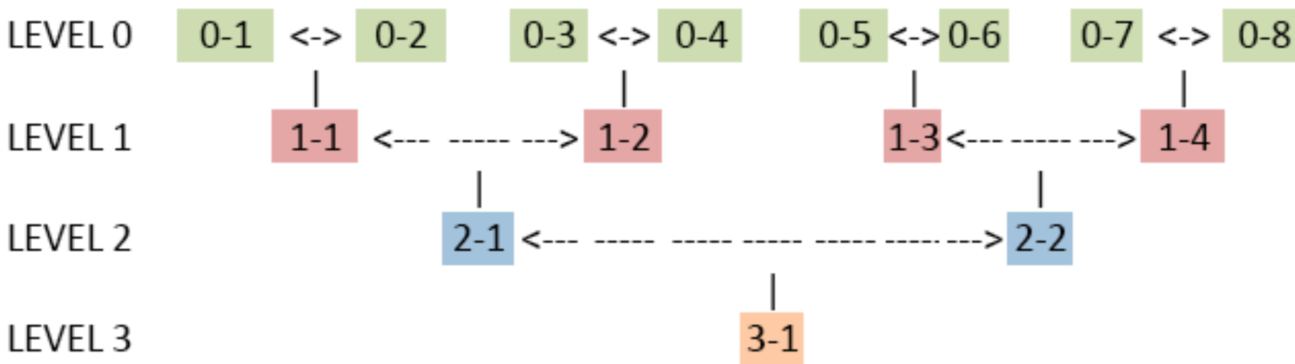


Fig. 3 – Processing tree for eight registered images (LEVEL 0) with numerical IDs.

APPENDIX A

Ephemeris of Solar System Dynamics

An *ephemeris* is a table of attributes of an astronomical body, such as a star, planet, satellite (moon or artificial), or comet. Attributes may include the physical properties of the body, such as mass, radius (polar and equatorial), and average density. Other attributes are time-dependent, such as celestial coordinates, magnitude, and distance in a spatial and temporal reference system. For our purposes, we will use an ephemeris that provides a table of key properties of Venus at times specified in the FITS image header. Our example is 16 FITS images recorded between 16:20 and 16:57 UTC on 13 December 2010.

The application we use is found at the JPL HORIZONS Web-Interface (http://ssd.jpl.nas.gov/horizons/). At the top of the HORIZONS Web-Interface is a section where the ephemeris type, target body, observer location, and time span are specified. In addition, it is necessary to specify settings for what table values are to be displayed. *Fig. 4* shows the Current Settings needed for this example.

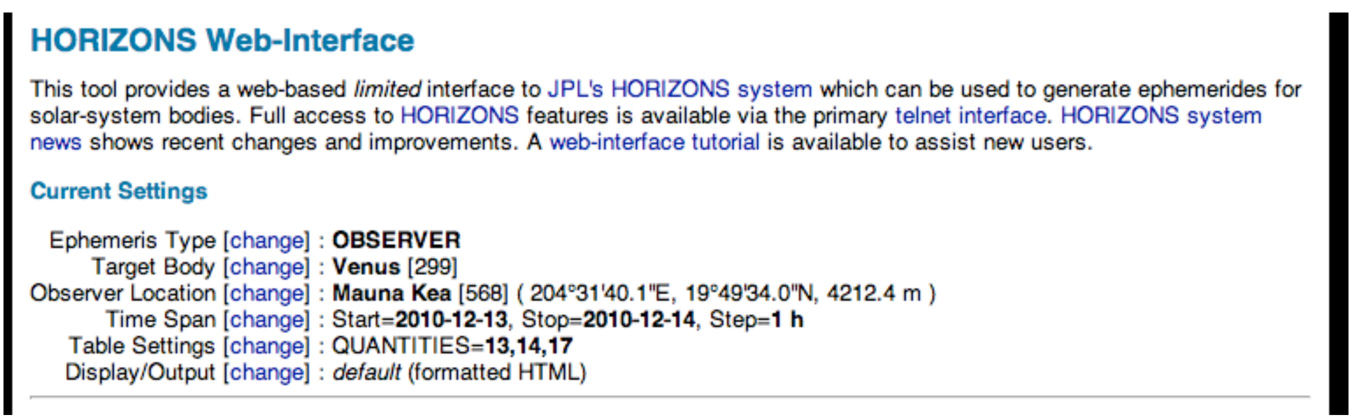


Fig. 4 – Settings required to generate an ephemeris of Venus as observed at the NASA IRTF on Mauna Kea, Hawaii on 13 December 2010. The ephemeris will show values of three quantities: (**13**) angular diameter of Venus in arc-sec (`Ang-diam`); (**14**) longitude and latitude of sub-observer point in Venus coordinates (`Ob-lon,Ob-lat`); and (**17**) position angle (degrees) of the North Pole (`NP.ang`) and its angular distance (arc-sec) (`NP.dist`) from the sub-observer point at one-hour intervals.

Fig. 5 shows a tabulation of hourly values of these quantities. The first thing that we notice is that the diameter of Venus changes very slowly between the first and last image of the sequence: ~0.01 arc-sec in the 27 minutes for an average diameter of 34.76 arc-sec. An independent determination of the *plate scale* found an average of 0.114 arc-sec/pixel. This means that the average diameter of the Venus image on the plate is 306 pixels.

```
*******************************************************************************
 Date__(UT)__HR:MN     Ang-diam Ob-lon Ob-lat   NP.ang   NP.dist
****************************************************************
$$SOE
 2010-Dec-13 00:00 *m  35.12172  37.74  -1.43  18.9650    -17.56
 2010-Dec-13 01:00 *m  35.09905  37.83  -1.43  18.9584    -17.54
 2010-Dec-13 02:00 *m  35.07638  37.93  -1.43  18.9517    -17.53
 2010-Dec-13 03:00 *m  35.05377  38.02  -1.44  18.9449    -17.52
 2010-Dec-13 04:00 Cm  35.03127  38.11  -1.44  18.9381    -17.51
 2010-Dec-13 05:00 Am  35.00892  38.20  -1.44  18.9312    -17.50
 2010-Dec-13 06:00  m  34.98676  38.29  -1.45  18.9242    -17.49
 2010-Dec-13 07:00  m  34.96480  38.39  -1.45  18.9172    -17.48
 2010-Dec-13 08:00  m  34.94306  38.48  -1.46  18.9101    -17.47
 2010-Dec-13 09:00  m  34.92154  38.57  -1.46  18.9031    -17.46
 2010-Dec-13 10:00  m  34.90021  38.66  -1.46  18.8961    -17.44
 2010-Dec-13 11:00     34.87905  38.76  -1.47  18.8891    -17.43
 2010-Dec-13 12:00     34.85803  38.85  -1.47  18.8822    -17.42
 2010-Dec-13 13:00     34.83709  38.94  -1.47  18.8753    -17.41
 2010-Dec-13 14:00     34.81619  39.03  -1.48  18.8685    -17.40
 2010-Dec-13 15:00     34.79527  39.12  -1.48  18.8618    -17.39
 2010-Dec-13 16:00 N   34.77429  39.22  -1.48  18.8551    -17.38
 2010-Dec-13 17:00 *   34.75320  39.31  -1.49  18.8484    -17.37
 2010-Dec-13 18:00 *   34.73197  39.40  -1.49  18.8418    -17.36
 2010-Dec-13 19:00 *   34.71058  39.49  -1.49  18.8352    -17.35
 2010-Dec-13 20:00 *   34.68902  39.58  -1.50  18.8286    -17.34
 2010-Dec-13 21:00 *   34.66729  39.67  -1.50  18.8220    -17.33
 2010-Dec-13 22:00 *   34.64541  39.76  -1.50  18.8154    -17.32
 2010-Dec-13 23:00 *m  34.62340  39.85  -1.51  18.8086    -17.31
 2010-Dec-14 00:00 *m  34.60131  39.94  -1.51  18.8018    -17.29
$$EOE
*******************************************************************************
```

Fig. 5 – Ephemeris for Venus 00:00 UTC on 13 December 2010 to 00:00 UTC on 14 December 2010. Table columns are defined in Fig. 6 and Fig. 7 shows notation used to determine solar and lunar properties at the given time.

```
 Ang-diam =
   The equatorial angular width of the target body full disk, if it were
fully visible to the observer.  Units: ARCSECONDS

 Ob-lon Ob-lat =
   Apparent planetographic ("geodetic") longitude and latitude (IAU2006 model)
of the center of the target disk seen by the OBSERVER at print-time. Light
travel-time from target to observer is taken into account. Latitude is the
angle between the equatorial plane and the line perpendicular to the reference
ellipsoid of the body (e.g., reflects body oblateness). Positive longitude
is to the east.  Units: DEGREES

 NP.ang NP.ds =
  Target's North pole position angle (CCW, or east, with respect to
direction of true-of-date Celestial North Pole) and its' angular distance
from the sub-observer point (center of disk) at observation time.
Negative distance indicates the planet's North pole is on the hidden
hemisphere.  Units: DEGREES and ARCSECONDS


 Computations by ...
     Solar System Dynamics Group, Horizons On-Line Ephemeris System
     4800 Oak Grove Drive, Jet Propulsion Laboratory
     Pasadena, CA  91109   USA
     Information: http://ssd.jpl.nasa.gov/
     Connect    : telnet://ssd.jpl.nasa.gov:6775  (via browser)
                  telnet ssd.jpl.nasa.gov 6775    (via command-line)
     Author     : Jon.Giorgini@jpl.nasa.gov

*******************************************************************************
```

Fig. 6 – Detailed discussion of definitions of `Ang_diam`, `Ob-lon`, `Ob-lat`, `NP.ang`, and `NP.dist`.

```
*******************************************************************************
Column meaning:

TIME

  Prior to 1962, times are UT1. Dates thereafter are UTC. Any 'b' symbol in
the 1st-column denotes a B.C. date. First-column blank (" ") denotes an A.D.
date. Calendar dates prior to 1582-Oct-15 are in the Julian calendar system.
Later calendar dates are in the Gregorian system.

  The uniform Coordinate Time scale is used internally. Conversion between
CT and the selected non-uniform UT output scale has not been determined for
UTC times after the next July or January 1st.  The last known leap-second
is used over any future interval.

  NOTE: "n.a." in output means quantity "not available" at the print-time.

SOLAR PRESENCE (OBSERVING SITE)
  Time tag is followed by a blank, then a solar-presence symbol:

        '*'  Daylight (refracted solar upper-limb on or above apparent horizon)
        'C'  Civil twilight/dawn
        'N'  Nautical twilight/dawn
        'A'  Astronomical twilight/dawn
        ' '  Night OR geocentric ephemeris

LUNAR PRESENCE (OBSERVING SITE)
  The solar-presence symbol is immediately followed by a lunar-presence symbol:

        'm'  Refracted upper-limb of Moon on or above apparent horizon
        ' '  Refracted upper-limb of Moon below apparent horizon OR geocentric
             ephemeris
```

Fig. 7 – Details about the time standard (UTC) and the solar and lunar presence at the specific time interval.

REFERENCE

Roberts, J., 2003, *Stacking Astronomical Images in PhotoShop*, 13 pp., *http://www.rocketroberts.com/astro/calibration.htm*